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Optical Interference Coatings

Characteristics of silica deposition from a high-frequency sweep e-beam system

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Abstract

Silica vapor distributions and the source erosion depths have been determined as a function of operating parameters of a high frequency sweep e-beam system.

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Introduction

Silica is the preferred low refractive index material for high laser damage threshold coatings at 1.06 µm. In order to coat large aperture optics, the thickness distribution of the evaporant plume should be as broad as possible while carve-in of the source avoided. High frequency sweep e-beam systems offer the possibility of more stable temperature profiles in the source for thickness uniformity; and programmable sweep controllers offers the possibility of more efficient erosion patterns in the source.

Experiment

Silica vapor distributions and erosion depths have been determined as a function of operating parameters of a high frequency sweep e-beam system. A design-of-experimental strategy was used on five operating parameters: evaporation rate, sweep speed, sweep pattern (pre-programmed), phase (pattern rotation speed), profile (dwell time as a function of radial position). A model was chosen to allow for second order (cross-term and square-term) affects. Twenty-eight runs were made under different conditions, and six replicate runs were made at the center of the parameter space.

The source material were synthetic silica boules machined to fit the e-gun hearth (6 cc). The e-beam system was a MDC e-vap 4000 system with their programmable sweep controller. Witness flats were placed symmetrically across a 24” diameter platen. The stationary platen was centered 24” above the e-gun crucible. Thickness measurements were made with a stylus profilometer. The power of the cosine function was calculated from the thickness data. Erosion depths were categorized into burn-through (of the boule), carve-in within a 1 mm, 5 mm and 7 mm of the bottom.

Results

Linear regression analysis of the data showed which of the parameters and second-ordered terms have statistically significant effects. The vapor distribution depends on the rate, speed, rate•speed, dwell•pattern terms, where N is the cosine power exponent:

$$N = 1.53 + 0.144\ \text{rate} - 0.106\ \text{speed} - 0.092\ (\text{rate} \bullet \text{speed}) - 0.114\ (\text{dwell} \bullet \text{pattern}).$$

The erosion, E is a function of rate, pattern and pattern^2, and speed and speed^2 terms:

$$E = 3.51 + 0.33 \text{ rate} + 0.28 \text{ pattern} - 0.28 \text{ speed} - 0.67 \text{ pattern}^2 - 0.67 \text{ speed}^2.$$

The signs on the coefficients indicate which values of the parameters are needed to optimize the cosine power exponent, N, and the erosion, E.

Starting with the equation for N, the product of (dwell•pattern) must be positive in order for N to be minimized. The two combinations of (dwell•pattern) that kept the coefficient negative were linear profile with a FIG8 pattern and a $1/R^2$ profile with a LINE pattern. Letting (dwell•pattern) = +1, the only terms remaining are rate and speed. The surface contour plot for N as a function of rate and speed is shown in Fig. 1. Figure 1 shows that broad vapor distributions can be obtained with low rates and slow (-1) speeds, high rates and fast (+1) speeds, and low rates and medium (0) speeds. At a fixed lower speed, the power exponent N does depend on rate as reported earlier.[1] Figure 1 also shows that the vapor distribution is less sensitive for fast speeds. This is advantageous to the coaters since rates do vary during a layer deposition.

An observation from all the N results is that, given the operating parameter ranges, the exponent value was $1.08 < N < 1.98$. Also, there was no interference of the e-beam on the coating thickness. It has been demonstrated that vapor flow is interrupted by the e-beam when operating conventional e-guns in a high deposition rate mode with metal alloys.[2]

Next, the erosion property will be optimized in a similar fashion. From analysis of the N function, only two patterns are available: a +1 pattern which represented a LINE pattern and a -1 pattern which represented a FIG8 pattern. Given that a “-1” value for pattern increases the value of the E, there are only the rate and speed terms left. Figure 2 shows the erosion contour plot as a function of rate and speed, where pattern = -1. The lines are the iso-erosion values (the higher the value the less carve-in). More efficient use of the source occurs at medium speeds and medium-to-high rates.

Overlaying the surface contour for N and E shows that an optimal setting for vapor distribution and good erosion occurs for a FIG8 pattern, medium speed, linear profile and a 5 Å/s rate. The shaded area in Fig. 3 shows the overlap of the regions where $N < 1.4$ and $E > 3.8$.

Conclusions

We have evaluated silica evaporation using a high frequency sweep e-beam system. The e-beam system produced vapor distributions where the cosine power exponent N is less than 1.98, and carve-in can be prevented. A design of experimental strategy approach showed the optimal settings for the vapor distribution and erosion to be FIG8 pattern, medium speed, linear profile and a 5 Å/s rate.

The procedure described here enables users of the high frequency e-beam systems to optimally locate the source in a vacuum system and understand which parameters have a major effect on the vapor distribution and source erosion.

Auspices

* This work was performed under the auspices of the U. S. Dept. of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

References

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2. Temescal, Physical vapor deposition, ed. R. J. Hill, 1986, BOC Group, p. 46.

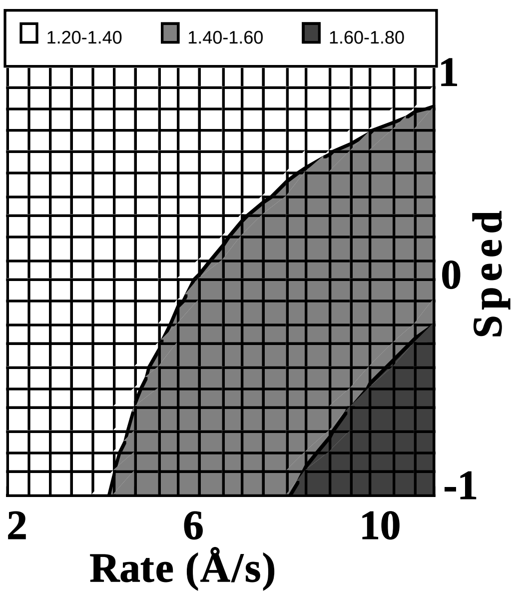

Fig. 1 Surface contour plot of the cosine power exponent, N. The product of (pattern • dwell) = +1.

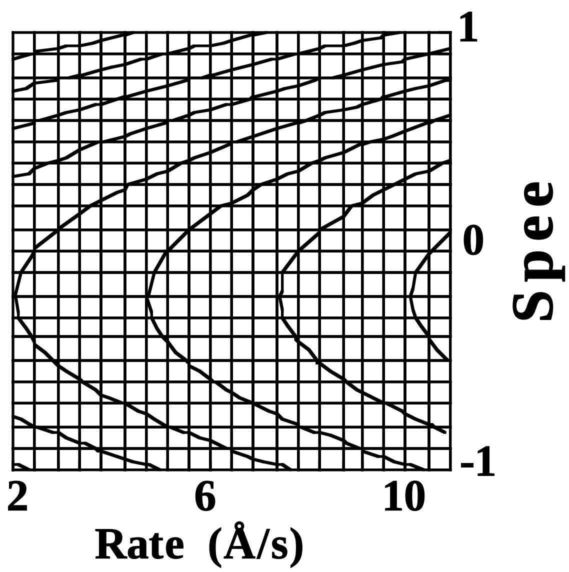

Fig. 2 Surface contour plot of erosion. The pattern was set to a -1 value, representing the FIG8 pattern.

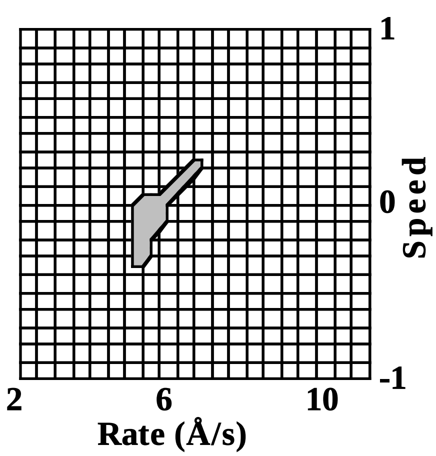

Fig. 3 Optimal parameters for N < 1.4 and E > 3.8. The shaded region is the overlap of these two conditions.